**Savannah River Site**
**Solid Waste Management Department**
**Consolidated Incinerator Facility Project**
**Operator Training Program**

# *CIF CHEMISTRY I* (U)

# Study Guide

***ZIOITX30***

**Revision 00**

_____
Training Authority / Date

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Facility Authority / Date

# FOR TRAINING USE ONLY

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# REVISION LOG

| REV. | AFFECTED SECTION(S) | SUMMARY OF CHANGE |
|---|---|---|
| 00 | All | New Issue. |

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# REFERENCES

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# LEARNING OBJECTIVES

## TERMINAL OBJECTIVES

T.O.1 Use the Periodic Table of the Elements to predict the Consolidated Incinerator Facility's outputs, given various categories of chemical inputs.

T.O.2 Given a scenario involving contact with a hazardous chemical, use chemical and biological principles to respond.

T.O.3 Given a scenario involving possible wastes to incinerate, predict their effects on the offgas system, especially pH and conductivity controls.

T.O.4 Given a scenario involving possible wastes to incinerate, predict their effects on emissions.

## ENABLING LEARNING OBJECTIVES

1. State which of the four fundamental forces in Nature is responsible for:
   a. Radioactive decay, fission and fusion
   b. Chemical reactions and properties

2. Name the subatomic particle that defines the differences between:
   a Two ions of the same element
   b. Two isotopes of the same element
   c. Two different elements

3. Name the chemical species that results from changing the number of
   a. protons,
   b. neutrons,
   c. or electrons of an atom

4. Compare the kinds of chemical reactions exhibited by
   a. Two ions of the same element
   b. Two isotopes of the same element

5. Given a Periodic Table of the Elements, locate:

    a. the synthetic human-made elements
    b. the elements whose principal isotopes are unstable
    c. the metals,
       non-metals
       and semiconductors
    d. the Halogen gases
    e. the Noble gases
    f. the characteristic element of organic compounds
    g. the **seven** diatomic gases

6. Given a Periodic Table of the Elements,
    a. Compare the combustibilty of nitrogen to the Noble (inert) gases
    b. Cite chemical formulas of typical acids, bases, alkalies or salts
       acids
       bases
       alkalies
       salts
    c. Contrast the physical properties
       of metals
       to those of non-metals
    d. State the form of any element, in its standard state.
    e. Predict the products of reaction between any acid or base
    f. Write the chemical symbol of any element, given its state as a solid, an ion in solution, or a gas.
    g. Compare the reaction products for the combustion
       of metals
       to those of non-metals
    h. List two properties of Nickel that account for the Rotary Kiln being made of Hastelloy C metal alloy-
    i. Given a reaction between two elements, recognize that the properties of the new compound are not predictable from the properties of the parent elements.

7. Use correct ionic chemical notation to
    a. **Distinguish between chlorine versus chloride.**
    b. Determine the physical state of $Cl_2$ versus $Cl^-$ .
    c. Distinguish between carbon dioxide gas and bicarbonate ions.
    d. Determine the physical state of $CO_2$ and $HCO_3^-$

8. Given the formula of an organic compound to be incinerated, trace the chemical and physical changes in its compounds throughout the facility, including:
   a. Their chemical behavior
   b. Their chemical formulas
   c. Their relative effects on process control of pH
   d. How their pH effects are alike or different.

9. $\mathbf{CO_2}\uparrow + \mathbf{H_2O} \quad \text{<--------->} \quad \mathbf{H^+} + \mathbf{HCO_3^-}$

   Given the equilibrium equation above showing the dissolving of $CO_2$ gas in water to form ions, predict the effect on that equation if:
   a. more $CO_2$ gas is added
   b. the pH setpoint of the pH controller is lowered
   c. if the temperature increases
   d) if the pH setpoint of the pH controller is raised

10. Given an equilibrium equation showing $CO_2$ dissolving in water, state
    a. which way the reaction will go, depending upon conditions such as
       1) temperature change,
       2) addition or removal of products during process changes
    b. whether or not the equation is balanced
    c. describe what physical state the chemical formulas in the equation indicate
    d. relate the reversibility of the equation to the difficulty it causes in process control
    e. predict the effects the equation has on process control

11. Given the names of any two elements that form compounds within CIF, and a Periodic Table of the Elements for reference:
    a. Write the chemical formula of the product they form using chemical symbols
    b. Using jelly beans and toothpicks, build a 3-dimensional model of a molecule of that compound
    c. Affix the chemical formula and name to the model.

12. Given the chemical name and formula of wastes acceptable in CIF,
    a. Classify their combustion products as gases or ashes or both
    b. Predict their effect on pH control in the Quench and the Scrubber Recirculation Tanks.

13. Write the ionic symbol of the species that makes acids and bases behave oppositely.

14. Compare the effects on pH of bases to alkalis.

15. Given formulas of any acid and any base, state that the acid-base pair can not be stored together or they are not compatible.

16. State the reason that these chemical categories can not be stored near each other, nor combined:
    a. Acids and bases -
    b. Oxidizing and reducing agents -
    c. Organic compounds and oxidizing agents
    d. Organic compounds and acids, especially nitric and sulfuric

17. Given the Periodic Table of the Elements and the formula $CO_2$, trace the chemical and physical changes that occur in carbon compounds throughout the facility, including:
    a. Their chemical behavior and formulas in the Kiln, SCC, Quench Vessel and Quench and Scrubber Recirculation Tanks.
    b. Their relative effects on process control of pH
    c. Their similarities or differences to chloride compounds

18. Given the formula of an organic chloride, trace the chemical and physical changes that occur in its compounds throughout the facility, including:
    a. Their chemical behavior and formulas in the Kiln, SCC,Quench Vessel and Quench and Scrubber Recirculation Tanks.
    b. Their relative effects on process control of pH

19. $\mathbf{Cl_2}\uparrow_{(aq)} + \mathbf{H_2O}_{(aq)} \text{ <------> } \mathbf{H^+}_{(aq)} + \mathbf{OCl^-}_{(aq)} + \mathbf{H^+} + \mathbf{Cl^-}$ (aqueous)

    Given an equilibrium equation for chlorine gas $Cl_2$ dissolving in water,
    a. Name the two acids chlorine forms when it dissolves in water.
    b. Predict the effect of driving off a gaseous reactant, by heating it
    c. Predict the effect of removing a product by neutralizing $H^+$ ions.
    d. Relate the action of hypochlorite ion, $OCl^-$ to the difficulty of checking a Quench Recirculation Tank's pH using color-changing pH paper.

20. Given the formula NaOH:
    a. Identify three CIF locations where contact with the chemical is possible.
    b. Write its correct chemical name (not the common name)
    c. Classify it chemically
    d. Explain why eye contact with NaOH is even worse than getting acid into the eye.
    e. State, in order of importance, the first three (3) actions to take if caustic gets into the eye.
    f. Define viscosity
    g. Explain how the viscous nature of concentrated NaOH helps to make pH control tricky.
    h. State the process purpose of NaOH in the CIF.
    i. Categorize the products of NaOH feed.

21. Given an equation for combustion of the following, balance the equation.
    a. propane
    **$C_3H_8$ (g) + ___ $O_2$ (g) ----> ___ $CO_2$ (g) + ___ $H_2O$ (liq)**
    propane
    b. benzene
    **$C_6H_6$ (g) + ___ $O_2$ (g) ----> ___ $CO_2$ (g) + ___ $H_2O$ (liq)**
    (benzene)
    or **___ $C_6H_6$ (g) + ___ $O_2$ (g) ----> ___ $CO_2$ (g) + ___ $H_2O$ (liq)**

22. Trace the physical and chemical changes throughout CIF, including the changes to the pH of water, for
    a. metals
    b. non-metals
    c. chlorides
    d. salts
    e. acids
    f. bases
    g. fuels
    h. organics

23. Given the situation of NaOH contacting an eye, detail the reason why any attempt to neutralize the base with an acid can only worsen the damage.

24. Explain two reasons why a person would not want to stop flushing their eyes to remove a chemical, just because the pain subsided.

25. Describe two likely adverse effects of going to an emergency room before flushing the eyes for 30 minutes.

26. Describe two ways of removing concentrated caustic if it contacts the front of a pullover sweatshirt.

27. Explain why eye damage is usually much more debilitating than skin contact of the same kind of chemical.

28. Defend the 30 minute flush time for eye contact with a chemical, despite the fact that the flush time for skin contact is 2 hours, based upon chemical kinetics.

29. Given a hypothetical case of acute or chronic overexposure from intentional failure to use PPE correctly, discuss the likely symptoms, delayed onset, and difficulties of diagnosis, depending upon the details provided.

30. Predict the effect that lowering the pH control setpoint, of both the Quench and Scrubber Recirculation Tanks, would have upon
    a. the amount of $CO_2$ gas in solution (dissolved in water)
    b. the amount of conductive solids in solution

31. Characterize the relationship between water purity and
    a. electrical conductivity
    b. electrical resistance

32. State what must be present in pure water, before it can carry a current.

33. State the chemical nature of a deposit on a conductivity probe or sensor that would cause
    a. falsely high conductivity readings
    b. falsely low conductivity readings

34. Write the chemical symbol of the positive (+1) ion that influences water's conductivity disproportionately.

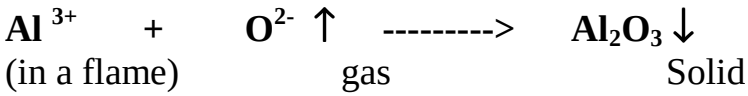
35. Write the chemical symbol of the negative (-1) ion that influences water's conductivity disproportionately.

36. Given protective plastic clothing contaminated with plutonium as an input to CIF, state whether the carbon or hydrogen of the plastic become radioactive sources.

37. Discuss how the process of evaporation causes scale deposits that can foul nozzles and heat transfer surfaces, referencing the boiling points of water and impurities in water.

38. a. List the three sets of competing forces in solutes and solvents.
    b. State which pair of attractions must be strongest in order for a solute to dissolve in a solvent.

39. Given an equation for an acidic gas forming in the Rotary Kiln, determine whether it is balanced or not.



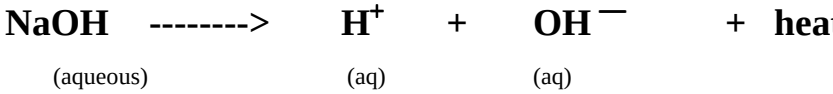

40. Given a situation describing taking a grab sample of a metal, state <u>both</u> the hazards of spilling that filled sample bottle.

41. State the storage incompatibilities of
    a. acids
    b. bases
    c. organics and fuels
    d. oxidizing or reducing agents

42. Given a situation involving sampling for a volatile organic compound, explain
    a. the safety hazard associated with leaving the sample in direct sunlight
    b. the probable inaccuracy introduced into that sample.

43. Cite a proof that molecules of a gas do not attract each other, while molecules of a liquid do.

44. State the three general steps for capturing carbon found in organic wastes.

45. 


    Given a chemical equation showing NaOH dissolving in water to form ions, and giving off heat,
    a. Write the chemical name for NaOH
    b. Categorize it as reversible or one-way
    c. List the three top personal safety concerns during caustic unloading.

46. Given a neutralization reaction, predict the interactive effect upon <u>conductivity</u> that caustic addition has, while it adjusts a Quench or Scrubber Recirculation Tank pH :
    a. from pH 2 to pH 7
    b. from pH 7 to pH 10

47. Explain what happens to all the caustic CIF adds to water, relating it to the products of neutralization reactions.

48. Explain the purpose of grab samples.

49. List two reasons a continuous sample could be misleading or not representative of the true contents of the tank sampled.

50. Contrast the class of impurities that are removable by filters, to the class of impurities that are detectable by conductivity instrumentation.

51. Given an "S-shaped" pH neutralization graph,
    a. explain the special pH control difficulties associated with the neutral zone at pH 7.
    b. compare the relative sensitivity of pH probes to the typical deadband of control valves.

52. Explain the sluggish response of a pH probe, right after a sharp swing to pH less than 2.0.

53. Contrast the visual indicators of pH when a glass probe
    a. has scratches on its surface due to abrasives in the fluid analyzed
    b. has broken

54. Describe the slow response time problem that develops when the sample fluid flow rate around a pH probe is excessive.

55. Write a chemical formula that shows
    a. a solid metal
    b. the same metal after corrosion dissolves it
    c. a hydrogen ion before it causes corrosion of a metal
    d. a hydrogen ion after it causes corrosion of a metal

56. Match examples of the following terms used to describe incompatible mixtures:
    a. polymerization
    b. precipitation
    c. coagulation
    d. explosion
    e. exothermal reaction
    f. toxic product
    g. oxidizing agents
    h. combustibles

57. State why the following combinations of chemicals are incompatible.
    a. Plutonium compounds and alkaline (high pH) compounds
    b. aluminum and caustic
    c. nitric acid or sulfuric with organic chemicals
    d. peroxides and organic chemicals
    e. acids and bases
    f. oxidizing agents and carbon-containing chemicals

58. Define the following fire safety terms
    a. Flash point
    b. Auto-ignition point
    c. flammable
    d. combustible
    e. evaporation
    f. vapor pressure
    g. surface area

59. Using the Student Safety Guide
    a. Identify four RCRA-regulated metals that are carcinogenic
    b. Locate $LD_{50}$ data on one of these regulated metals:
    c. Define the term $LD_{50}$
    d. Using the LD50 and their own body weight, calculate the amount of a RCRA metal, in ounces, that could kill a person of their size
    e. List three routes of entry for toxic substances.

60. Define these terms related to CIF's discharge permits
    a. % ash
    b. Specific Gravity
    c. Density
    d. Viscosity
    e. Chlorine
    f. Btu -
    g. grain
    h. particulate

61. Contrast the measures gram and grain.

62. State the practical and regulatory significance of these requirements for incineration:
    a. % ash
    b. Specific Gravity
    c. Density
    d. Viscosity
    e. chlorine
    f. Btu
    g. 0.02 grains/dry standard cubic foot

63. Given the physiological symptoms of choking, uncontrollable coughing and lung disease, identify the chemical name and formula of one possible cause.

**ENABLING LEARNING OBJECTIVES (with brief details)**

1. State which of the four fundamental forces in Nature is responsible for:
   a. Radioactive decay, fission and fusion - Nuclear or Strong Force
   b. Chemical reactions and properties - Electromagnetic Force

2. Name the subatomic particle that defines the differences between:
   a Two ions of the same element - $p^+$
   b. Two isotopes of the same element - $n^o$
   c. Two different elements - $e^-$

3. Name the chemical species that results from changing the number of
   a. protons, - new element
   b. neutrons, - isotope of the same element
   c. or electrons of an atom - dif. ion of the same element

4. Compare the kinds of chemical reactions exhibited by
   a. Two ions of the same element - form different compounds
   b. Two i**s**otopes of the same element - form **s**ame compounds

5. Given a Periodic Table of the Elements, locate:

   a. the synthetic human-made elements - afterUranium, symbol U

   b. the elements whose principal isotopes are unstable - after Lead, symbol Pb

   c. the metals, - left of the stair step pattern
   non-metals - right side of the stairstep border
   and semiconductors - on the borderline

   d. the Halogen gases - Group VIIB
   Symbols $F_2$ not $Fl_2$, $Cl_2$,$Br_2$,$I_2$,$At_2$

   e. the Noble gases - Group VIII
   all are inert; have full shell $e^-$

   f. the characteristic element of organic compounds - Carbon = C

   g. the **seven** diatomic gases - Hydrogen on left plus 6 gases
   that form a **"7"** going down Group **VII** B
   $H_2$ $N_2$ $O_2$ $F_2$ (**not $Fl_2$ )** $Cl_2$ **(not $CL_2$)** $Br_2$ $I_2$

6. Given a Periodic Table of the Elements,

   a. Compare the combustibilty of nitrogen to the Noble gases
   - Noble gases have full shells so they **can not** combust.
   - Nitrogen **does not** combust.

   b. Cite chemical formulas of typical acids, bases, alkalies or salts
   acids - begin with hydrogen = H
   bases - end with hydroxide= $OH^-$
   alkalies - no simple rule, don't bother
   salts - metal and a non-metal in a compound like NaF= a rat poison,or KCl = "lite salt"

   c. Contrast the physical properties
   of metals - high mp, very high bp, hard, conduct electricity and heat, solid @ room temp
   to those of non-metals - think of the opposite of metals above

   d. State the form of any element, in its standard state.
   - you already can find both the Noble gases and the 7 diatomic "gases."- standard state = at room temp. and 1 atm. pressure (ambient conditions)

   e. Predict the products of reaction between any acid or base
   **- a salt plus pure water**

   f. Write the chemical symbol of any element, given its state as a solid, an ion in solution, or a gas.
   **Solid Iron = Fe** (metal at room temp.)
   **Dissolved or Corroded Iron = $Fe^{2+}$ or also $Fe^{3+}$**
   **Superscripts show electrical charge above and to the right**
   **Superscripts show ions not atoms; atoms are neutral**
   **Superscripts usually refer to ions in solutions, or in a flame**

   g. Compare the reaction products for the combustion
   of metals - Metal oxides have very **high boiling points** (stay solid), and turn water **basic**.
   to those of non-metals - Think of the opposites of the above trends

h. List two properties of Nickel that account for the Rotary Kiln being made of Hastelloy C metal alloy-

Nickel = Ni makes iron and steel extremely corrosion resistant; only fluorine, as a gas $\mathbf{F_2}$ or as an ion, $\mathbf{F^-}$ attacks Hastelloy C. Ni makes steel stronger when steel is at very high temperatures

i. Given a reaction between two elements, recognize that the properties of the new compound are not predictable from the properties of the parent elements.

A blue solid and a yellow gas **won't** make a green liquid.

7. Use correct ionic chemical notation to
   a. **Distinguish between chlorine versus chloride.**

**chlorine gas = $\mathbf{Cl_2}$;**
**chloride ions in solution = $\mathbf{Cl^-}$**

   b. Determine the physical state of $Cl_2$ versus $Cl^-$ .

chlorine is a gas; chloride is an ion in solution

   c. Distinguish between carbon dioxide gas and bicarbonate ions.

**carbon dioxide gas = $\mathbf{CO_2}$**
**bicarbonate ions** in solution = $\mathbf{HCO_3^-}$

   d. Determine the physical state of $CO_2$ and $HCO_3^-$

$CO_2$ is a gas;
$HCO_3^-$ is an ion ion solution

8. Given the formula of an organic compound to be incinerated, trace the chemical and physical changes in its compounds throughout the facility, including:
   a. Their chemical behavior

Example: $C_6H_6$ contains two non-metals, so it combusts to form two gases, not any ashes

   b. Their chemical formulas

Example: $C_6H_6$ produces $CO_2$ and water, $H_2O$

   c. Their relative effects on process control of pH

non-metals combust to form acidic gases requiring more caustic (NaOH)

   d. How their pH effects are alike or different.

9. $\mathbf{CO_2}\uparrow + \mathbf{H_2O} \quad \text{<--------->} \quad \mathbf{H^+} + \mathbf{HCO_3^-}$

Given the equilibrium equation above, showing the dissolving of $CO_2$ gas in water to form ions, predict the effect on that equation if:

   a. more $CO_2$ gas is added

-drives reaction to the right forming more acidic $H^+$ ions

b. the pH setpoint of the pH controller is lowered

Lowering the pH setpoint is same as making it more acidic. Making it more acidic is equivalent to adding more $H^+$ ions. Adding a substance on one side (right) makes it shift oppositely (to the left, forming more $CO_2$ gas.

c. if the temperature increases

Higher temp. will drive off gases - the $CO_2$ on the left side Removing substance from the left makes the reaction speed up toward the left to replace what's leaving.

d) if the pH setpoint of the pH controller is raised

Raising pH setpoint is making it basic = less acidic. Less acidic means removing $H^+$ ions from the right side. Removing substances on the right causes the reaction to speed up toward the right, replenishing what's being removed.

10. Given an equilibrium equation showing $CO_2$ dissolving in water, state

a. which way the reaction will go, depending upon conditions such as

1) temperature change,

Heating drives off $CO_2$ gas from the left, so it drives it toward the left forming more $CO_2$ gas.

2) addition or removal of products during process changes

Adding a product to one side drives it the opposite direction.

Removing a product from one side drives it to same side as the substance leaving the equation.

b. whether or not the equation is balanced

Example: count the no. of carbon atoms on the left side of the arrows = 1; do the same for C on the right = 1 also; move on to H, you see two on the left, two on the right so it's balanced. Repeat for oxygen, get 3 on left and 3 on right. That's all the elements shown, so the equation is balanced.

c. describe what physical state the chemical formulas in the equation indicate

**$CO_2$ $\uparrow$ at room temp, carbon dioxide is a gas**

**$H_2O$ is a liquid at room temp.**

**$H^+$ refers to an ion in solution, here an acid**

**$HCO_3^-$ refers to an ion in a solution.**

d. relate the reversibility of the equation to the difficulty it causes in process control

When we change the rate we generate or add $CO_2$ , or the amount of $H^+$ that we remove with caustic, the equilibrium moves in the opposite direction. There is a time delay between the time we make a change and see its full effects.

e. predict the effects the equation has on process control

Reversible chemical equations can force a control room operator to live with a certain amount of swing back and forth across setpoint, something not seen, for example, in controlling a simple heating loop.

11. Given the names of any two elements that form compounds within CIF, and a Periodic Table of the Elements for reference:
    a. Write the chemical formula of the product they form using chemical symbols

    Example: $Ca^{2+}$ and $OH^-$ form $Ca(OH)_2$

    b. Using jelly beans and toothpicks, build a 3-dimensional model of a molecule of that compound

    Example: the only sequence they'll connect is: H---O---Ca---O---H, where the three elements are shown in 3 colors, and the hydrogen jelly beans only have one chemical bond (toothpick) connecting them, while the oxygen jelly beans have two bonds and the lone calcium has two toothpicks.

    c. Affix the chemical formula and name to the model.

    Print $Ca(OH)_2$ on a piece of paper, affix it to the model.

12. Given the chemical name and formula of wastes acceptable in CIF,
    a. Classify their combustion products as gases or ashes or both

    Example: Given calcium sulfate, $CaSO_4$ then look up Ca on the Periodic Table. Calcium is a metal so it leaves the Kiln as ash. Look up S. Sulfur is a non-metal so it leaves the SCC as an acidic gas. Oxygen does not combust so it just leaves as oxygen - not an acidic gas, just as oxygen, $O_2$.
    b. Predict their effect on pH control in the Quench and the Scrubber Recirculation Tanks.

    Example: The Sulfur above will become an acidic gas, and more caustic will be required than if we were burning fuel only.

13. Write the ionic symbol of the species that makes acids and bases behave oppositely.

    acids form $H^+$ ions in water
    bases form $OH^-$ ions in water

14. Compare the effects on pH of bases to alkalis.

Both bases and alkalis raise pH. The Dept. of Transportation labels both of them "Corrosives" with placards.

15. Given formulas of any acid and any base, state that the acid-base pair can not be stored together or they are not compatible.

16. State the reason that these chemical categories can not be stored near each other, nor combined:
    a. Acids and bases -

The reaction produces a lot of HEAT

    b. Oxidizing and reducing agents -

HEAT FOLLOWED BY: fire, an explosion, toxic fumes and incendiary sparks, or believe it or not, a white-hot meltdown of a steel drum, in seconds.

    c. Organic compounds and oxidizing agents

FIRE

    d. Organic compounds and acids, especially nitric and sulfuric

sulfuric acid, FIRE
nitric acid, EXPLOSION OR FIRE

17. Given the Periodic Table of the Elements and the formula $CO_2$, trace the chemical and physical changes that occur in carbon compounds throughout the facility, including:

    a. Their chemical behavior and formulas in the Kiln, SCC, Quench Vessel and Quench and Scrubber Recirculation Tanks.

Carbon = C. All carbon compounds in the Kiln will produce some mixture of mostly carbon dioxide = $CO_2$, plus some carbon monoxide = CO. From the Secondary Combustion Chamber, $CO_2$ gas exits. The $CO_2$ gas dissolves in Quench Vessel spray water, forming an acid which has to be neutralized in the Scrubber Recirculation Tank.

    b. Their relative effects on process control of pH

Whether from fuel alone, or organic waste, all carbon compounds will require caustic to neutralize the acidic gas formed.

    c. Their similarities or differences to chloride compounds

Carbon compounds form one acid, chloride compounds form two different acids in the Scrubber when they dissolve in water.

18. Given the formula of an organic chloride, trace the chemical and physical changes that occur in its compounds throughout the facility, including:

    a. Their chemical behavior and formulas in the Kiln, SCC,Quench Vessel and Quench and Scrubber Recirculation Tanks.

    Example: solvent trichloroethylene = $C_2H_4Cl_3$
    Organic chlorides will form CO, $CO_2$ and $Cl_2$ in the Kiln. Only $CO_2$ and $Cl_2$ emerge from the Secondary Combustion Chamber. When they dissolve in Quench water, $CO_2$ forms one acid, and $Cl_2$ forms two acids. All three acids must be neutralized in the Scrubber Recirculation Tank.

    b. Their relative effects on process control of pH

    All three acids must be neutralized in the Scrubber Recirculation Tank.

19. $Cl_2\uparrow_{(aq)} + H_2O_{(aq)} \text{ <------> } H^+_{(aq)} + OCl^-_{(aq)} + H^+ + Cl^-$ (aqueous)

    Given an equilibrium equation for chlorine gas $Cl_2$ dissolving in water,

    a. Name the two acids chlorine forms when it dissolves in water.

    1) hydrochloric acid = HCl
    2) hypochlorous acid = HOCl

    b. Predict the effect of driving off a gaseous reactant, by heating it

    A temperature increase
    Driving off chlorine gas from the left speeds the reaction to the left, replenishing the $Cl_2$.

    c. Predict the effect of removing a product by neutralizing $H^+$ ions.

    Removing $H^+$ ions from the right forces the reaction to speed up moving to the right meaning more $Cl_2$ chlorine gas dissolves in the water.

    d. Relate the action of hypochlorite ion, $OCl^-$ to the difficulty of checking a Quench Recirculation Tank's pH using color-changing pH paper.

    We make bleach in both Recirculation Tanks. The solution can bleach the pH paper to yellow then white, giving a wrong color indication. (If evaporated to dryness the two Recirculation Tanks' solutions would deposit solid NaOCl. The $Na^+$ comes from the caustic we add, NaOH. The $OCl^-$ forms when chlorine $Cl_2$ gas dissolves in water.

20. Given the formula NaOH:
    a. Identify two CIF locations where contact with the chemical is possible.
    (caustic storage tank)
    (Quench Recirculation Tank)
    (scrubber - ejector nozzle)
    (Blowdown Hold Tanks)
    (Offgas trench)
    b. Write its correct chemical name (not the common name)
    sodium hydroxide
    c. Classify it chemically
    It's a base
    d. Explain why eye contact with NaOH is even worse than getting acid into the eye.
    In some cases, an acid hitting the eye forms a protein scab that can slow further penetration briefly. Caustic just keeps on dissolving the eyeball.
    e. State, in order of importance, the first three (3) actions to take if caustic gets into the eye.
    1.
    2.
    3. Seek medical attention
    f. Define viscosity
    Resistance to flow
    g. Explain how the viscous nature of concentrated NaOH helps to make pH control tricky.
    Viscous materials take extra time to get into solution and dissolve completely. This introduces lag time or delay between the operator action of increasing caustic feed, and the effects seen as a change in pH.
    h. State the process purpose of NaOH in the CIF.
    The Process purpose is to trap acid gases by converting them into dissolved ions in water.
    i. Categorize the products of NaOH feed.
    NaOH reacts with acids in the process to form a salt plus pure water. The salt is bicarbonate of soda.

21. Given an equation for combustion of the following, balance the equation.
    a. propane
    **$C_3H_8$ (g) + 5 $O_2$ (g) ------> 3 $CO_2$ (g) + 4 $H_2O$ (liq)**
    propane
    b. benzene
    **$C_6H_6$ (g) + 7 1/2 $O_2$ (g) ------> 6 $CO_2$ (g) + 3 $H_2O$ (liq)**
    (benzene)
    or **2 $C_6H_6$ (g) + 15 $O_2$ (g) ------> 12 $CO_2$ (g) + 6 $H_2O$ (liq)**

22. Trace the physical and chemical changes throughout CIF, including the changes to the pH of water, for
    a. metals - forms ash
    b. non-metals - form acidic gases so they require neutralization by sodium hydroxide, NaOH
    c. chlorides - form two kinds of acidic gases so they require neutralization by sodium hydroxide, NaOH
    d. salts - the metal part forms an ash
       the non-metals form acidic gases so they require neutralization by sodium hydroxide, NaOH
    e. acids the hydrogen part forms water
       the rest of the molecule will at least form some acid gas
    f. bases the hydroxide portion might form hydrogen peroxide = $H_2O_2$ and then water, $H_2O$
       the rest of the molecule will form an ash
    g. fuels the carbon will form an acid gas
       the hydrogen will form water
    h. organics the carbon will form an acid gas
       the hydrogen will form water

23. Given the situation of NaOH contacting an eye, detail the reason why any attempt to neutralize the base with an acid can only worsen the damage.
    It will only destroy the parts of the eye where there is no caustic.

24. Explain two reasons why a person would not want to stop flushing their eyes to remove a chemical, just because the pain subsided.
    1. The eye has very few nerves; eyes can be operated on without using an anaesthetic.
    2. Caustic might have destroyed the nerve endings (loss of communication). There is no way to know which caused the pain to stop.

25. Describe two likely adverse effects of going to an emergency room before flushing the eyes for 30 minutes.
    IF you get there, WHEN you get there, the damage will be complete.
    WHEN you get there, the emergency nurse is going to flush your eyes with saline solution for thirty minutes before the doctor can examine you, but only 5% of the benefit of that flush will be realized.

26. Describe two ways of removing concentrated caustic if it contacts the front of a pullover sweatshirt.

1...Remove it in the shower
2...Cut if off, or, pull it off from the back to the front.

27. Explain why eye damage is usually much more debilitating than skin contact of the same kind of chemical.

Eye tissue does not regenerate the way skin does.

28. Defend the 30 minute flush time for eye contact with a chemical, despite the fact that the flush time for skin contact is 2 hours, based upon chemical kinetics.

Chemicals react with eyes to the extent of 90% completion in 15 minutes, and 95% completion in thirty minutes. Eye damage is over with fast. Skin damage underneath the epidermis can continue for two or three days without the longer flush time. The longer time is needed to rehydrate the skin as well as cool the reaction, slowing it while the water dilutes the chemical that penetrated deeply.

29. Given a hypothetical case of acute or chronic overexposure from intentional failure to use PPE correctly, discuss the likely symptoms, delayed onset, and difficulties of diagnosis, depending upon the details provided.

Acute overexposure effects are apparent rapidly. Chronic overexposure at lower levels can trigger different symptoms **many months** after exposure. It's almost impossible to diagnose because you can't remember what you did differently six or eight months ago.

30. Predict the effect that lowering the pH control setpoint, of both the Quench and Scrubber Recirculation Tanks, would have upon
    a. the amount of $CO_2$ gas in solution (dissolved in water)

    Drives off $CO_2$ into the atmosphere

    b. the amount of conductive solids in solution

    More ions combine to form neutral $CO_2$ so it lowers conductivity

31. Characterize the relationship between water purity and
    a. electrical conductivity

    - opposites: high purity water has low conductivity.

    b. electrical resistance

    - synonyms or interchangeable terms (equivalent terms)

32. State what must be present in pure water, before it can carry a current.

ions (dissolved impurities that are ionized)

33. State the chemical nature of a deposit on a conductivity probe or sensor that would cause
    a. falsely high conductivity readings

    - rust path between electrodes conducts

    b. falsely low conductivity readings

    - air, oil, sand (silica) = harder to figure out.

34. Write the chemical symbol of the positive (+1) ion that influences water's conductivity disproportionately.

    $H^+$

35. Write the chemical symbol of the negative (-1) ion that influences water's conductivity disproportionately.

    $OH^-$

36. Given protective plastic clothing contaminated with plutonium as an input to CIF, state whether the carbon or hydrogen of the plastic become radioactive sources.

    The radioactive source is a metal, plutonium, Pu. Metals form ashes in the Rotary Kiln. The organics form gases, such as $CO_2$ and $H_2O$, but they are not radioactive sources afterward.

37. Discuss how the process of evaporation causes scale deposits that can foul nozzles and heat transfer surfaces, referencing the boiling points of water and impurities in water.

    Impurities dissolved in water usually have much higher boiling points than water does. So when evaporation occurs, only the water leaves. The minerals stay behind and become more concentrated. When they exceed the solubility of that compound, they form a solid deposit.

38. a. List the three sets of competing forces in solutes and solvents.

    Example: sugar in water.
    Water for water and sugar for sugar
    Water for sugar

    b. State which pair of attractions must be strongest in order for a solute to dissolve in a solvent.

    To dissolve, the one UNLIKE attraction (here, water for sugar) must be stronger than the other two attractions.

39. Given an equation for an acidic gas forming in the Rotary Kiln, determine whether it is balanced or not.

**$Al^{3+}$** + **$O^{2-}$** ↑ ---------> **$Al_2O_3$** ↓
(in a flame) gas Solid

This one example is not balanced. There is one Al on the left, but two on the right. There's one oxygen on the left, but three on the right. Matter is not created out of thin air in a reaction, so it needs balancing.

40. Given a situation describing taking a grab sample of a metal, state <u>both</u> the hazards of spilling that filled sample bottle.

Metal analyses require a few ml of an acid in the grab sample bottle to keep any metals in the sample dissolved so they don't plate out on the container. Spilling the sample contaminates once with whatever hazardous chemicals were in the sample, plus the corrosive acid added to pickle or preserve the metal.

41. State the storage incompatibilities of
    a. acids - not near **bases** nor **organics** nor reducing agents
    b. bases - not near **acids**
    c. organics and fuels - not near **oxidizing agents** nor **acids**
    d. oxidizing or reducing agents - not near **each other**

42. Given a situation involving sampling for a volatile organic compound, explain
    a. the safety hazard associated with leaving the sample in direct sunlight
    Flammable substance might ignite
    b. the probable inaccuracy introduced into that sample.
    The volatile organic compound might escape the container either before it is opened or when it is first opened.

43. Cite a proof that molecules of a gas do not attract each other, while molecules of a liquid do.

Open a container of gas, it expands to fill a larger container. Liquids do not expand to fill their containers because attractive forces between molecules within a liquid hold each other back.

44. State the three general steps for capturing carbon found in organic wastes.

Combust it to $CO_2$ gas
Dissolve the $CO_2$ in water, creating an acid neutralize the acid fixing the C as bicarbonate ions in solution.

45. **NaOH --------> $H^+$ + $OH^-$ + heat**
(aqueous) (aq) (aq)

Given a chemical equation showing NaOH dissolving in water to form ions, and giving off heat,

a. Write the chemical name for NaOH

sodium hydroxide

b. Categorize it as reversible or one-way

one-way

c. List the three top personal safety concerns during caustic unloading.

1. Eyes
2. Inhalation
3. Skin protection

46. Given a neutralization reaction, predict the interactive effect upon <u>conductivity</u> that caustic addition has, while it adjusts a Quench or Scrubber Recirculation Tank pH :

1). from pH 2 to pH 7

conductivity decreases this direction

2. from pH 7 to pH 10

conductivity increases this direction

47. Explain what happens to all the caustic CIF adds to water, relating it to the products of neutralization reactions.

most of it is converted into pure water; the rest into NaCl, table salt, or $NaHCO_3^-$ bicarbonate of soda.

48. Explain the purpose of grab samples.

To verify the representativeness of continuous samples; to make sure what's in the tank is the same as what's going through the automated sampler.

49. List two reasons a continuous sample could be misleading or not representative of the true contents of the tank sampled.

Problem in mixing action
Sample is changing (components reacting or incompatible)

50. Contrast the class of impurities that are removable by filters, to the class of impurities that are detectable by conductivity instrumentation.

Filters remove suspended solids, not dissolved solids.
Conductivity detects dissolved solids, not suspended solids.

51. Given an "S-shaped" pH neutralization graph,

a. explain the special pH control difficulties associated with the neutral zone at pH 7.

If you add equal amounts like uniform droplets of sodium hydroxide (caustic, NaOH) solution, you don't get equal changes in the pH. As you get nearer pH 7, each droplet has much greater impact on pH change.

b. compare the relative sensitivity of pH probes to the typical deadband of control valves.

pH probes can measure a 100,000-fold change in $H^+$ ion concentration in a second. A typical valve has a deadband of 1% meaning it may be 1,000 times less sensitive to change in control action

52. Explain the sluggish response of a pH probe, right after a sharp swing to pH less than 2.0.

The semi-permeable glass tip can have its pores and internals fouled with $H^+$ ions. They can only flow out of the glass by diffusion, a slow process. Until the acid gets out of the glass probe surface, the probe is insulated from the process stream.

53. Contrast the visual indicators of pH when a glass probe

a. has scratches on its surface due to abrasives in the fluid analyzed

Small, slow, back and forth drift in reading, even of a constant solution.

b. has broken

Large, sudden swings in reading, even if the process is constant.

54. Describe the slow response time problem that develops when the sample fluid flow rate around a pH probe is excessive.

Excessive flow rate pulls reference fluid out of the probe; which was designed to slowly diffuse outward. As the reference fluid level drops the response slows (increased time needed to balance)

55. Write a chemical formula that shows
    a. a solid metal

       Example: Fe

    b. the same metal after corrosion dissolves it

       $Fe^{2+}$

    c. a hydrogen ion before it causes corrosion of a metal

       $H^+$

    d. a hydrogen ion after it causes corrosion of a metal $H_2$

56. Match examples of the following terms used to describe incompatible mixtures:
    a. polymerization - Plutonium at high pH polymerizes
    b. precipitation
    c. coagulation
    d. explosion
    e. exothermal reaction
    f. toxic product
    g. oxidizing agents
    h. combustibles

57. State why the following combinations of chemicals are incompatible.
    a. Plutonium compounds and alkaline (high pH) compounds

       polymerization and precipitation

    b. aluminum and caustic

       heat and $H_2$ gas which is explosive/flammable

    c. nitric acid or sulfuric with organic chemicals

       sulfuric acid = fire; nitric acid = explosion

    d. peroxides and organic chemicals

       explosions

    e. acids and bases

       heat

    f. oxidizing agents and carbon-containing chemicals

       fire or explosion

58. Define the following fire safety terms
    a. Flash point

       -The minimum temperature at which the vapor coming from a liquid makes an ignitable mixture with air. **In short, the temp. a liquid ignites**.

b. Auto-ignition point

-The minimum temperature at which a flammable mixture will ignite from its own heat source or contact with a hot surface without a flame or spark. **In short, the temp. something ignites from heat alone without flame or spark.**

c. flammable

-In short, a substance that ignites below 100°F. In some definitions, below 140°F.

d. combustible

-In short, a substance that ignites between 140°F and 200°F.

e. evaporation

-At a given temperature, some molecules of a liquid are moving faster than others. A percentage of the fastest ones can escape the fluid, becoming a gas. Most organic (carbon-containing) liquids like benzene and gasoline.evaporate faster and at lower temperatures than inorganic liquids.

f. vapor pressure

-The pressure at the surface of a liquid (or solid) caused by molecules escaping into the atmosphere above.

g. surface area

-Exposing more surface area or increasing the temperature of a fluid increases its evaporation rate.

59. Using the Student Safety Guide

a. Identify four RCRA-regulated metals that are carcinogenic

(As, Be, Cd, Cr)

b. Locate $LD_{50}$ data on one of these regulated metals:

(Sb, Ba, Pb, Hg,Ni,Ag,Se,Tl)

c. Define the term $LD_{50}$

Lethal Dose for 50% of a population tested.

d. Using the LD50 and their own body weight, calculate the amount of a RCRA metal, in ounces, that could kill a person of their size

Example: If a lethal dose is 500 ppm and I weigh 250 pounds, multiply the numbers together and move the decimal 6 places left (125,000 lbs. becomes 0.125) Then convert to ounces: 0.125 times 16 oz/lb = 2 oz. Then 2 oz. of that substance in a single dose kills 50% of a test population.

e. List three routes of entry for toxic substances.

inhalation, ingestion, absorption through the skin.

60. Define these terms related to CIF's discharge permits
    a. % ash

    -solid residue that won't combust. Usually it's a metal oxide such as $Na_2O$ which obviously is already in a combusted form. ("Can't burn twice.")

    b. Specific Gravity

    - Ratio or comparison of a substance's density to some reference substance. Since solids and liquids reference to water, specific gravity is the same number as the solid or liquid's density. It only differs in that S.G. has no units of measurement.

    c. Density

    -Ratio or fraction of a substance's mass divided by its volume (how much space it occupies).

    d. Viscosity

    -Resistance to flow

    e. Chlorine

    Gas that forms two acids in the scrubber; regulated; forms dioxins when incinerated.

    f. Btu -

    The amount of heat energy needed to raise the temperature of one pound of water (about a pint) by one deg. F.

    g. grain - 0.064 grams, or about a sixteenth of one gram.
    h. particulate - solid suspended (filterable) in air.

61. Contrast the measures gram and grain.

    -A gram is the amount of powder in a "Sweet 'N Low" packet, so a grain is about one-sixteenth of such a packet.

62. State the practical and regulatory significance of these requirements for incineration:
    a. % ash

    - clogs nozzles or overloads HEPA filters.

    b. Specific Gravity

    - high S.G. will cause excessive head pressure at base of fiberglass tank, exceeding design limit (rupture)

    c. Density

    - exceeding this causes excessive mass flow through the Rotary Kiln then temp. spiking.

d. Viscosity
- difficulty in pumping

e. chlorine
- dioxans formed during combustion, runaway low pH in scrubber.

f. Btu
- Overtemperature

g. 0.02 grains/dry standard cubic foot
- health problems in neighboring communities and at SRS

63. Given the physiological symptoms of choking, uncontrollable coughing and lung disease, identify the chemical name and formula of one possible cause.
- sulfur dioxide, $SO_2$

# TRAINEE WORKBOOK